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"Estoy Explorando Science": Emerging Bilingual Students Problematizing Electrical Phenomena Through Translanguaging

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Abstract

As science education continues to embrace science-as-practice, equitable science learning environments must value and leverage emergent bilingual students' ways of communicating. This study investigates the translanguaging practices of a group of elementary-aged emergent bilingual students while they problematized electrical phenomena. Building on asset-oriented theories for supporting student learning, I utilize translanguaging as a theoretical and pedagogical lens for understanding how emergent bilingual students leverage their full semiotic repertoires for productive disciplinary engagement. The study took place in an out-of-school program focused on creating opportunities for students to problematize electrical phenomena, specifically electrical resistance. I present a close analysis of students constructing models of electric flow through a circuit and how electrical resistance regulates that flow. The findings also include evidence that students engaged in different kinds of translanguaging practices when problematizing electrical phenomena and co-constructing knowledge with each other and the instructor. Specifically, students drew from and used multiple linguistic and non-linguistic semiotic resources for communicating their models. Finally, the findings suggest that the instructor's pedagogical moves and own translanguaging practices implicitly signaled to students when and how to participate in translanguaging practices themselves. The findings emphasize the importance of desettling what counts as productive forms of communication in science for elementary-aged emergent bilingual students by eschewing pedagogical models that police discursive boundaries. Therefore, equitable science learning environments must create opportunities for emergent bilingual students to leverage their full semiotic repertoires for meaning-making, by inviting and valuing multiple languages and gestures.

Keywords*: Science Education; Elementary Science; Equity; Emergent Bilingual Students; Translanguaging; Electricity; Gestures*

Introduction

Research in science education has suggested that effective science learning environments provide students with opportunities to engage in epistemic practices in order to figure out and develop conceptual understanding about natural phenomena (e.g., Duschl, 2008; Ford, 2008; Ford & Forman, 2006; Lehrer & Schauble, 2006a). This commitment to "science-as-practice" (Berland et al., 2016; Lehrer & Schauble, 2006b; Manz, 2015; Stroupe, 2014) is supported by sociocultural and cultural-historical approaches that frame learning as the acquisition of diverse repertoires of cultural practices that are developed and valued by specific communities (Lave & Wenger, 1991; Nasir et al., 2014); science-as-practice has been codified into current national educational policy (National Research Council, 2012) and standards (e.g., NGSS Lead States, 2013). These reforms, and the research upon which they are based, emphasize the importance of students making contributions to knowledge-building, spontaneously participating in knowledge-driven processes, and attending to each other's thinking, through engaging in disciplinary work. However, most science learning environments (K-12 or out-of-school time) seldom make these kinds of opportunities and resources available to students from historically non-dominant communities (Bang et al., 2017; Rosebery et al., 2010; Vossoughi et al., 2016), such as emergent bilingual students. These students are often referred to as English Language Learners (ELLs), but I build on the work of critical scholars (Escamilla & Hopewell, 2010; García, 2009b; Gutiérrez & Orellana, 2006) who propose the term "emergent bilingual students" (García, 2009b) to foreground and value these students' bilingualism, and highlight that they have a right to learn content beyond developing English fluency. It is also important to recognize that these students represent multiple linguistic and cultural backgrounds, making them a heterogeneous group with varied resources and needs.

In our attempts to make science learning environments equitable and accessible to emergent bilingual students, it is important to consider how to create opportunities for valuing and leveraging these students' discursive practices in the service of making sense of the natural world. *Translanguaging* (García, 2009a; Otheguy et al., 2015) offers a theoretical and pedagogical lens for understanding how emergent bilingual students leverage their full *semiotic repertoires* (Blackledge & Creese, 2017; Kusters et al., 2017; Li, 2018), a collection of linguistic and non-linguistic resources, without regard for socially and politically constructed discursive systems. Researchers and educators who are committed to justice-based education have called for learning environments to become "translanguaging spaces" (Li, 2011), where students from various biographical, historical, and linguistic backgrounds draw from and use new and multiple modes for making meaning. A growing body of research shows that creating opportunities for learners to engage in translanguaging supports their learning, particularly for elementary-aged students' literacy skills (Collins & Cioè-Peña, 2016; Kleyn & Yau, 2016; Martínez, 2010).

While *translanguaging* has a decades-long tradition in sociolinguistics and bi-/multilingual education, it is relatively new to the field of science education. Thus far, researchers have predominantly focused on how elementary-aged emergent bilingual students use their full semiotic repertoire when reading and writing about science content (e.g., Espinosa & Herrera, 2016; Poza, 2016; Stevenson, 2013, 2015). Though reading and writing are certainly important practices for making sense of the natural world, this research does not address how translanguaging supports students engage in a broader set of scientific epistemic practices, such as constructing and refining models. Foundational research in science education suggests that emergent bilingual students learn best when leveraging their conceptual, linguistic, and cultural resources when making sense of the natural world (Ballenger, 2004; Rosebery, Ogonowski, DiSchino, & Warren, 2010; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). Nevertheless, a lacuna remains with regards to how to support emergent bilingual students engage in disciplinary work, through leveraging their full semiotic repertoires. This presents an opportunity to explore how students engage in familiar discursive practices as they co-construct knowledge about natural phenomena.

The purpose of this study is to contribute to the growing body of literature on equitable science teaching and learning by developing a more nuanced understanding of how to create the conditions that can support emergent bilingual students' translanguaging practices, as well as how to support these students leverage linguistic and non-linguistic resources when making sense of the natural world. Specifically, this study investigates the translanguaging practices of a group of elementary-aged emergent bilingual students when problematizing (Engle, 2012) electrical phenomena in an out-of-school science program that I (Enrique) designed and implemented, and whether my pedagogical moves made the learning environment a translanguaging space, or not.

The article is structured as follows. First, I present a brief review of the asset-oriented literature on supporting emergent bilingual students in their learning of science, followed by a brief review of the research on leveraging semiotic repertoires when translanguaging. I then describe the study context and participants, as well as the process of collecting and analyzing the data. Third, I present findings that describe the translanguaging practices students engaged when sharing their ideas about electrical phenomena, drawing on communicative resources from their semiotic repertoires. The findings further focus on the factors that made the environment a translanguaging space. The article ends with a discussion of theoretical, analytical, and pedagogical implications for creating equitable science learning environments through supporting students' translanguaging practices.

Theoretical Framing

Designing for engaging in productive epistemic meaning-making

This study builds on sociocultural and cultural-historical approaches of learning and development. Specifically, through this lens, learning is a series of processes that occur within specific activities, and at the intersection of multiple positions and experiences, with the intent of developing diverse repertoires of practices that represent ways of knowing and acting that accomplish knowledge-building purposes by specific communities (Gutiérrez & Rogoff, 2003; Lave & Wenger, 1991; Nasir et al., 2014). This definition frames science learning within the turn towards "science-as-practice," which expects and requires that learning environments create opportunities for *all* students to learn science through meaningfully engaging in the epistemic practices (Berland et al., 2016; Manz, 2015). Engaging in these practices supports learners to develop a set of ways of knowing and acting to understand the natural world, as well as their conceptual understanding of natural phenomena.

The focus on learning as engaging through practices poses a unique opportunity for researchers and educators to approach students' meaning-making of the natural world from a more equitable perspective and consider the wide range of intellectual practices that have been historically excluded from science learning environments. The work of Nasir, Warren, Rosebery, and C. Lee (Nasir et al., 2014) is particularly helpful for imagining what meaning-making practices should look like in equitable learning environments. Specifically, Nasir and her coauthors conceive of learning and development "as the acquisition throughout the life course of diverse repertoires of overlapping, complementary, or even conflicting cultural practices" (2014,

p. 686), and particularly learning within disciplinary contexts to extend beyond a "body of conceptual knowledge (…) involves critical engagement with epistemological assumptions, points of view values, and dispositions" (2014, p. 689). Similarly, Rosebery and her collaborators (Rosebery et al., 2010) argue that, in order to counter prescriptive and hegemonic versions of education, it is important to frame learning as a process where "heterogeneous meaning-making come into contact (…) to generate new understandings, extend navigational possibilities, and adapt meaning-making practices to new forms and functions" (2010, p. 324).

From this perspective, equity and justice are not about sameness of experiences or even outcomes (Nasir et al., 2014). Instead, equitable and transformative science learning environments should build on students' diverse meaning-making repertoires (Bang et al., 2017), pushing back against the "rather narrow range (or repertoire) of ways of speaking, knowing, acting, and valuing that are privileged" in most science learning environments (2017, p. 34). Therefore, expansive science teaching and learning happen in learning environments that: (1) notice students' meaning-making repertories; (2) support students' meaning-making through building on those repertoires; and (3) the community engages in diverse meaning-making that draws clear and purposeful connections between students' communities and scientific knowledge and knowing (Bang et al., 2017, p. 39). From this perspective, the goal is to design for equitable science learning opportunities that are heterogeneous in nature (Rosebery et al., 2010), bringing together and coordinating disciplinary practices and knowledge with students' experiences and histories, rather than one replacing the other.

Productive Disciplinary Engagement (PDE) can guide our efforts to design science learning environments that create these kinds of expansive opportunities for "students' deep involvement in and progress on concepts and/or practices characteristic of the discipline" being learned (Engle, 2012, p. 172), through identifying and building on students' diverse meaning-making repertoires. As a conceptual framework, PDE is useful for (re-)imagining equitable science education because it holds together student engagement, disciplinary aspects of science learning, and contextually-relevant forms of productive participation. Specifically, the framework positions *all* learners as agentive constructors of knowledge who are capable of collectively wrestling with the uncertainties inherent in understanding the natural world. The commitment to positioning students as producers of knowledge is foundational for justice-centered science pedagogies (e.g., Morales-Doyle, 2017) that invite students to coordinate multiple ways of knowing to address the complex problems that stem from injustices in their communities. PDE can also serve as a useful framework for designing learning environments where students can meaningfully engage in activities that come address specific issues and practices of disciplinary work. For example, Engle and Conant (2002) designed an activity where students had to decide whether orcas were actually whales; their engagement was both disciplinary, as they marshalled multiple forms of evidence to wrestle with a complex taxonomical question, and productive, as they developed sophisticated counter-/arguments about taxonomical classifications that led to new and deeper questions about biology. However, Engle and Conant avoided prescribing what forms of activity count as disciplinary, "given differences in institutional positioning, societal purposes, desired outcomes, temporal horizons, prior experiences, and other constraints" (Engle, 2012, p. 164) that shape science education, as well as scientific enterprise. Instead, they expect educators and researchers to wrestle with what aspects of disciplinary practices their designs would ask students to engage in, acknowledging that different disciplinary topics and sub-disciplines require different considerations.

Engle and Conant (2002) proposed four main design principles for science learning environments that support students to experience PDE. First, instructors should encourage students to *problematize content* through posing questions and authoring explanations, rather than simply accepting facts. Specifically, Engle (2012) defines *problematizing* as any "individual or collective action that encourages disciplinary uncertainties to be taken up by students" (2012, p. 175), in particular "uncertainty about what to do, uncertainty about what to conclude, uncertainty about how to justify what one is doing or concluding, and uncertainty caused by competing alternatives about any of the three prior issues" (Engle, 2012, p. 176). While related to "sensemaking" (e.g. Kapon, 2017; Odden & Russ, 2019), which focuses more on the process of iteratively and collaboratively building and refining explanations in order to address gaps and/or inconsistencies in understanding how and why phenomena occur, *problematizing* is more concerned with the complex questions and wonderments that arise when students choose to engage with disciplinary content and make progress towards figuring out what is going on.

A disciplinary practice I value for learning to problematize phenomena and their inherent uncertainties is modeling, which allows learners to explain and predict how and why phenomena occur (National Research Council, 2012). Through bridging the gap between ideas and the world, modeling serves to externalize students' reasoning and conjectures, an activity that is central for problematizing and understanding the natural world (Gouvea & Passmore, 2017; Schwarz et al., 2009). As a practice, modeling entails deciding which parts of the system being problematized should be included or excluded, as well as the underlying relationships and processes that give rise to observable phenomena; this is how the "how and why" phenomena occur are refined by learners (Louca & Zacharia, 2012; Russ et al., 2008). For these reasons, creating opportunities for learners to propose, evaluate, and refine models is crucial for high-quality learning opportunities (Lehrer & Schauble, 2006a), often missing in learning environments for minoritized youth. Moreover, creating models as tools for inquiry that include representations of current understandings of a system (Gouvea & Passmore, 2017) is enriched when inviting a host of representational and communicative strategies. Specifically, models serve their epistemic aims better when information about the entities and processes in a system can be represented in ways that unpack complexities and increase accessibility to the ideas (Grapin, 2019; Schwarz et al., 2009). Recently, Grapin (2019) pushed back against the over-emphasis on scientific vocabulary and argued that the practice of modeling created productive opportunities for emergent bilingual learners to convey meaning and engage in co-constructing knowledge about natural phenomena through deploying multiple modes (e.g., writing, speaking, drawing, gesturing). Moreover, creating and refining models encourages learners to consider the potentials and limitations of different modes for representing and sharing observations and ideas (Grapin, 2019), in turn developing their metarepresentational competencies (Lehrer & Schauble, 2006a). For this reason, centering modeling as a practice for emerging bi-/multilingual learners to engage in invites a range of semiotic resources that it will enrich the process of inquiry.

Second, environments need to *give students authority* to define and address problems, as well as become stakeholders in the process of co-constructing knowledge. Third, students should be held *accountable to others and disciplinary norms*, particularly by how their work is responsive to what community insiders and outsiders have established. Finally, it is necessary to make available *relevant resources*, intellectual and/or material, to support students in their meaning-making and participation. The attainment of productive disciplinary engagement relies on the dynamic balance between all four principles, with some easily linked due to their contributions to students' meaning-making. For example, few and/or inadequate resources can make problematizing phenomena insurmountable, while oversaturating the environment with resources can reduce the tasks' complexity; both scenarios decrease students' possibilities of experiencing PDE (Engle, 2012; Manz, 2015; Otero, 2004; Varelas et al., 2008).

Framing students' ways of communicating through the lens of heterogeneity

The principles and outcomes of PDE rest on the possibility that students can engage in fruitful and meaningful discourse, particularly forms of discourse that approximate those of the discipline (Engle & Conant, 2002). From a sociocultural perspective, discourse is conceptualized as a complex socio-cultural-historical activity that mediates communication between people and how they come to understand the social and natural worlds (Gee, 2001; Gutiérrez, 2008; Vygotsky, 1986). Therefore, discourse is key to learning science through engaging in practices, specifically productive disciplinary engagement: collaboratively problematizing phenomena, authoring ideas, and co-constructing knowledge; its centrality is heightened when engaging in discourse through leveraging learners' communicative resources. To this end, it is crucial that science learning environments foster and support a discursive community where students attend to each other's ideas and to the community's standards of reasoning (Michaels et al., 2008; Michaels & O'Connor, 2012). And, in accordance with conceptualizing learning as a complex series of processes at the intersection of multiple ways of knowing, equitable conceptualizations of discourse must account for the wide range of communicative practices.

The question of how to conceptualize emergent bi-/multilingual students' ways of communicating their observations and reasoning about natural phenomena has been in constant change. Earlier on, some researchers argued that emergent bilingual students exhibited cognitive and communicative strategies of limited effectiveness and benefitted from explicit instruction on science content and discourse. Therefore, the most effective instructional strategy was to design for *congruence*: bridging the perceived gap between students' ways of talking and English-only scientific discourse (e.g., Lee et al., 1995; Lee & Fradd, 1998). It is easy to understand how this line of thinking was prevalent in the field during the 1990s, a time characterized by restrictive language policies have impeded the use of languages like Spanish in schools across the United States (Rumberger & Tran, 2010). Moreover, in the U.S., science learning environments, from elementary grades to higher education, have historically privileged English as the sanctioned language of instruction and meaning-making (Mazak & Herbas-Donoso, 2014; Stevenson, 2013; Tonkin, 2011). For the past two decades, however, researchers have reframed their stances to recognize the function of the linguistic resources emergent bi-/multilingual students bring to science learning environments (e.g., González-Howard & McNeill, 2016; Kang et al., 2017; Lee et al., 2013; Lee & Buxton, 2011). For example, O. Lee et al. (2013) warn against how implementing the Next Generation Science Standards (NGSS) could be inequitable for emergent bi-/multilingual students, without providing instructional guidance that support students develop English-language skills, like learn how to talk like a scientist (e.g., vocabulary, sentence structure). Similarly, Brown has focused on designing learning activities in which emergent bi-/multilingual students meaningfully learn scientific vocabulary through building on their ways of talking, as a way to avoid the perceived perils community-based discourses pose towards learning science and/or developing a positive science identity (Brown, 2004; Brown & Ryoo, 2008). Still, the idea that emergent bi-/multilingual students need access to academic discourses in order to learn, given that their own discursive practices are insufficient are common among science education researchers and educators.

The departure from overt deficit-oriented perspectives has created an opportunity for science researchers and educators to focus their efforts on building on the linguistic resources of emergent bi-/multilingual students. Specifically, building on a commitment towards academic discourses as productive tools for knowing, these efforts have focused on developing pedagogical strategies that support emergent bi-/multilingual students to develop scientific discourses through leveraging their existing linguistic resources (e.g., Brown & Ryoo, 2008; Jung & Brown, 2016; Kang et al., 2017; Lee et al., 2013; Lee & Fradd, 1998; Wu et al., 2019). This line of inquiry has focused on framing emergent bi-/multilingual students' linguistic resources as productive building blocks upon which students can develop more scientist-like communicative practices. In other words, this line of inquiry takes an asset-based approach to teaching, learning, and researching how emergent bi-/multilingual students learn and use academic discourses. The question remains, however, how these approaches frame equity and justice as discursive homogeneity in science learning environments, averting hetoregenity.

If our goal is to promote equity and justice for *all* students, then our research and pedagogy must account for the heterogeneous nature of learning processes that sit at the intersection of multiple ways of knowing (Nasir et al., 2014). We understand that research agendas and pedagogies that promote homogeneity tend to concern themselves with "how to 'fit' students constructed as 'other' by virtue of their race/ethnicity, language, or social class" (Ladson-Billings, 1995, p. 467) into what the dominant group would consider to be appropriate or productive. Striving for homogeneity has clear implications for the way we frame discourse in science learning environments, particularly deciding what kinds of discourses are considered to be productive and appropriate for problematizing and meaking meaning of the natural world. This is not to say that academic discourses, as sociolinguistic tools, do not have a place in supporting studens problematize phenomena; on the contrary. As some have argued (e.g., Gee, 2004, 2008; Lemke, 1990), the discourse that scientists have developed as part of their meaning-making practices is productive for problematizing and understanding natural phenomena, and they can also be productive for students to be socialized into and engage with. What we must be cautious of, however, are attempts to normalize what "scientific discourse" is supposed to sound and/or look like – different scientists, from different sub-fields, cultures, and/or geographical locations will deploy a range of ways of communicating in the service of collaborative meaning-making (e.g., Ochs et al., 1994). We must also be wary of specialized discourse becoming the end goal of teaching and learning science, particularly when a persistent focus on academic terminology often results in excluding emergent bi-/multilingual learners from participating in meaningful intellectual activity (Grapin, 2019). Centering academic English, especially at the expense of other forms of communicating, tends to misrecognize the sense-making repertoires that emergent bi-/multilingual students bring to the learning environment (Flores & Rosa, 2015; García & Kleifgen, 2019). Moreover, seeing students' ways of talking as steppingstones towards academic discourses, often perceived as more sophisticated, can gloss over the ideas and observations are communicating, and/or how they are doing so. Therefore, it is necessary to move towards learning environments that create opportunities for new ways of problematizing natural phenomena to emerge, particularly at the intersection of multiple ways of communicating and where academic discourse is one of the many resources at students' disposal (Gutiérrez et al., 1995; Rosebery et al., 2010; Warren et al., 2001).

As science educators strive to design equitable learning environments, we need to understand how the design features rooted in heterogeneous meaning-making can create opportunities for minoritized students to engage in epistemic work, particularly co-constructing mechanistic models of physical phenomena. PDE can help researchers investigate what kinds of resources should be made available, invited, and leveraged to support emergent bilingual students problematize and author ideas about the natural phenomena they observe.

Translanguaging: making meaning through leveraging multiple communicative resources

The first step towards positioning emergent bilingual students as agents in their science learning and breaking away from deficit-oriented narratives is understanding the complexity of communicative resources that mediate their collaboration and meaning-making. This framing is particularly important for understanding and valuing emergent bilingual students' multifaceted discursive practices as assets for investigating and making sense of the natural world (Rosebery et al., 2010; Warren et al., 2001). *Translanguaging* offers an opportunity for science education pedagogy and research to broaden our understanding of what communicative resources are productive for making sense of natural phenomena, and how emergent bilingual students leverage them for co-constructing scientific knowledge. Otheguy, García, and Reid (2015) define translanguaging as, "the deployment of a speaker's full linguistic repertoire without regard for watchful adherence to the socially and politically defined boundaries of named (and usually national and state) languages" (2015, p. 281). This definition is grounded in the position that "named languages" (e.g., English, Spanish, Arabic), the conglomerates of lexical and structural resources that make up the *linguistic repertoires*, are socially and politically constructed, rather than based on lexical or structural features (Otheguy et al., 2015). Through rejecting socially constructed barriers between languages, translanguaging rejects a monoglossic framing of bi-/multilingualism notion that these multilingual learners have multiple separate whole languages that are kept segregated and used independently. The *trans* prefix denotes the practice of transcending arbitrarily defined linguistic barriers and hierarchies (García & Kleyn, 2016), and leveraging different linguistic resources for communicative and meaning-making purposes. Finally, it is useful to recognize that translanguaging occurs when "people engage as they bring into contact different biographies, histories, and linguistic backgrounds" (Blackledge & Creese, 2017, p. 250). This specification bounds translanguaging effectively to the interaction between interlocutors who represent different named languages, although some would argue the construct also encompasses communication between people with regional, class, and/or stylistic variations of the same named language (Li, 2018).

Proponents of bi-/multilingual education call for learning environments to become "translanguaging spaces" (Li, 2011) where students can use the full extent of their linguistic repertoire for creative and critical purposes. Specific to K-12 classrooms, García and Sylvan (García & Sylvan, 2011) describe translanguaging as, "the process by which bilingual students and teachers engage in complex discursive practices in order to 'make sense' of, and communicate in, multilingual classrooms" (2011, p. 389). Thus, translanguaging requires pedagogical practices that support students to leverage their full linguistic repertoires in the service of learning (García & Kleyn, 2016): (i) constructing collaborative and cooperative task structures; (ii) leveraging multilingual and multimodal learning materials; and (iii) enacting translanguaging pedagogical practices that give bi-/multilingual students permission to "bring their language practices to the surface and into the open" for meaning-making (2016, p. 23). The pedagogical strategies that García and Sylvan call for are consonant with PDE, particularly the emphasis on collaborative meaning-making that positions students as agents who should be allowed to leverage the multiple communicative resources that they bring to the learning process.

As many have argued, human communication is possible due to the reliance on multiple modalities that are coordinated across multiple semiotic fields (Goldin-Meadow, 1999; Goodwin, 2000), not just written and/or spoken modes of communication. Sociolinguist and bilingual education researchers have recently highlighted the multimodal nature of translanguaging practices, including non-linguistic resources as part of the communicative repertoires bi-/multilingual speakers draw from when deploying translanguaging practices (Blackledge & Creese, 2017, 2020; García & Li, 2014; Kusters et al., 2017; Li, 2018). Specifically, Wei Li urges bilingual education research and educators to thinking of language as a "multisensory and multimodal semiotic system interconnected with other identifiable but inseparable cognitive systems" (Li, 2018, p. 20). Embodied communicative practices and linguistic communicative practices are integral to each other, given that language processing cannot happen independently from auditory and visual processes (Blackledge & Creese, 2017, 2020; Li, 2018).

In an attempt to continue expanding the forms of communication over the construct of translanguaging, Kusters and her collaborators (Kusters et al., 2017) intentionally blur the boundaries that separate linguistic from non-linguistic communicative resources. Kusters *et al.* (2017) recognize that relegating non-linguistic resources has created a hierarchy where some semiotic resources are more prized than others. This kind of ranking can reify power asymmetries that restrict which communicative resources are available for meaning-making and, ultimately, undermine the goal of creating opportunities for speakers to communicate through leveraging their full semiotic repertoires. To disrupt this hierarchy, these authors suggest the construct *semiotic repertoire* to describe the collection of both linguistic and non-linguistic resources bi-/multilingual speakers deploy when engaging translanguaging practices. Similarly, Blackledge and Creese (2017, 2020) define translanguaging as a process of selecting communicative resources from a broad semiotic repertoire, rather than being limited to only choosing between named languages. Resisting separating the linguistic from the embodied, these authors argue that the "corporeal dimension of translanguaging" (Blackledge & Creese, 2017, p. 250) – gestures, eye gaze, body positioning – plays a crucial and inseparable role in supporting bi-/multilingual speakers to communicate and make meaning of their world. To clarify, however, the presence of embodied communicative practices is a necessary condition of translanguaging, but not a sufficient one; in other words, two monolingual Spanish speakers sharing meaning through eye gaze and body positioning *would not* be considered translanguaging, given that these interlocutors share a similar linguistic background.

Leveraging the full semiotic repertoire: Students making sense of the natural world through gestures

Among the possible non-linguistic semiotic resources that learners rely on when collaborative making meaning, *gesturing* is both common and powerful. Goldin-Meadow (1999) argues that gestures can help speakers express ideas that may be challenging to communicate through speech, thus providing speakers with an additional representational system that can both reduce cognitive effort and serve as a tool for thinking. Similarly, Sfard (2009) suggests that gestures can support effective communication by ensuring interlocutors are speaking about the same object, thus strengthening the symbolic and symbiotic relationship between gestures and speech. Finally, McNeill suggests that gestures and speech occur simultaneously and, in fact, gestures that accompany speech present similar semantic meanings and play similar pragmatic functions (McNeill, 1992). Because of these affordances, gestures and language are intimately linked and are co-expressive and, therefore, gestures are integral to communication, rather than communicative placeholders to be substituted by written or spoken words[1].

Thus far, much of the research on students' use of linguistic and non-linguistic resources for meaning-making that is relevant to science education has taken place in two separate scholarly branches and learning contexts. On one hand, research on the translanguaging practices of multilingual students has focused on these students' use of linguistic resources, particularly when speaking, reading, and/or writing. On the other hand, the relevant research on how students use gesture for communicating their ideas has mostly focused on monolingual English-speaking students, particularly in science. Through reviewing work from these two separate traditions, my aim is to begin charting a way to consider both linguistic and gestural semiotic resources for equitable teaching and learning science, particularly for emergent bi-/multilingual learners.

While relatively new to the field of science education, some research has already been done to understand how elementary-aged emergent bilingual students engage in translanguaging practices in science learning environments. For instance, Poza (2016) studied how LatinX emergent bilingual students in an elementary classroom engaged in translanguaging practices when learning about the periodic table of elements. Poza observed that students moved between websites in English and worksheets in Spanish when writing a report about the elements, as well as using nouns in English and Spanish when finding examples of elements in their surroundings. Based on these findings, Poza concluded that the emergent bilingual students he observed did not adhere to socially constructed barriers that separate English and Spanish, and instead drew from a broad linguistic repertoire when collaborating and learning content. Similarly, Espinosa and Herrera (2016) explored the translanguaging practices of LatinX emergent bilingual 6th-graders when learning about states of matter. Encouraged by their teacher, Ms. Montoya, students used both English and Spanish during whole-class discussions about their observations, when writing notes that synthesized the information they read, and to learn academic vocabulary. Espinosa and Herrera concluded that Ms. Montoya made her science lessons a translanguaging space, where her students used multiple linguistic resources that were salient and productive when co-constructing knowledge about the states of matter. Finally, while not building on the construct of translanguaging, González-Howard and McNeill (2016), as well as Kang and her collaborators (Kang et al., 2017), found that middle school students were able to construct better scientific (counter-)arguments when allowed to use linguistic resources from both Spanish and English.

Other studies have investigated science classrooms that restricted students' use of their full linguistic repertoire. Stevenson (2013, 2015) focused on how emergent bilingual students in an elementary school, which offered bilingual programs, used Spanish and English when learning science. Stevenson observed that the science classroom was characterized by an intentionally monoglossic approach to bilingualism (i.e., keeping Spanish and English separate), as the teacher required that students spoke English when engaging in the science activities. These

[1] Although not focusing on gestures, Scott Grapin proposed the construct "weak version of multimodality" to describe how educators of bi-/multilingual learners consider non-linguistic modes of communication (e.g., gestures) as "a crutch or temporary scaffold to be removed once students develop proficiency with more privileged forms of communication, namely, oral and written language" (Grapin, 2019, p. 33). Grapin argues that this logocentrism (inadvertently) reifies deficit-based views that emergent bi-/multilingual learners' semiotic repertoires lack the necessary sophistication to make meaning within curricular content areas, such as science.

studies concluded that students spoke English predominantly when interacting with the teacher, particularly during didactic activities, whereas students spoke Spanish predominantly when interacting with other students, particularly during laboratory activities. Stevenson inferred that, even when restrictive language policies of the science classroom were not enforced, students purposefully chose which named language to use when engaging in different learning activities.

These studies offer a window into how equitable responsive teaching can create translanguaging spaces where emergent bilingual students leverage a wide range of linguistic resources (e.g., named languages) when learning science. First, this line of inquiry highlights the importance of allowing multilingual students to draw from their full linguistic repertoires when engaging in learning about science. Rather than keeping Spanish and English separate, for example, students engaged more deeply with each other's ideas and content when they could move freely between them. Secondly, these studies point to the consequences of language policies and expectations that limit multilingual students' use of a broad range of linguistic resources. As Stevenson found, when teachers restrict which linguistic resources can be used when learning science can reify a monoglossic view of bilingualism, as well as prevent the science learning environment from becoming a transformation translanguaging space. Despite their valuable contributions, however, most studies on translanguaging in science focus solely on reading and writing about science, which represent a small portion of the epistemic practices needed when investigating the natural world. Therefore, further research is needed to continue developing how equitable responsive teaching can support emergent bilingual students' translanguaging for engaging in epistemic practices of the discipline.

One relevant study was conducted by Ünsal and her collaborators (Ünsal et al., 2018), who were concerned with how emergent bilingual students relied on non-linguistic resources when communicating ideas, particularly when overcoming "language limitations" (2018, p. 122). Focusing on 3rd and 7th graders whose repertoires included resources associated with Swedish and Turkish, the authors found that "using bridging gestures enabled the student to communicate science when words were missing" (2018, p. 136), and that both peers and teachers were attentive and responsive to the meaning emergent bilingual students communicated through gesturing. Unfortunately, there is a dearth of research on how emergent bilingual students engage in translanguaging practices through gesturing when making sense of physical phenomena. As Blackledge and Creese point out, much of the research on multimodality has focused on monolingual speakers (Blackledge & Creese, 2017), which can provide insight into how emergent bilingual students could use gestures when learning science.

Focusing on monolingual-English speaking students, Roth (1996, 2001) has described how students share their ideas through gestures. For example, when studying how middle school students made sense of simple machines, Roth (1996) observed that students used gestures when describing how a pulley system could reduce the amount of force needed to move heavy objects, as they pointed to a diagram of the machine they were studying. Similarly, when investigating how high schoolers used a visual display to understand accelerated motion, Roth (2001) observed that students performed gestures when describing how an object moved. Specifically, Roth observed how a student pointed to different parts of the screen when talking about the object and its path, and performed gestures that resembled the object's trajectory. These studies led Roth to conclude that gestures are central to sharing and making sense of ideas about physical phenomena, rather than auxiliary and dispensable; the hand can represent imperceptible entities, while the hand's motion can stand for the activity the entities are involved in.

Building on this research, I am interested in exploring how designing learning environments to be translanguaging spaces can help reframe what equitable science learning means for emergent bilingual students. Specifically, this study seeks to understand how translanguaging spaces can create opportunities for emergent bilingual students leverage linguistic (e.g., named languages) and non-linguistic (e.g., gestures) resources when engaging in epistemic practices of science, particularly when problematizing phenomena through authoring mechanistic models of electrical phenomena. This study contributes to research on equitable science teaching and learning by identifying and describing how a group of elementary-aged emergent bilingual students in an out-of-school science program drew from their semiotic repertoires when problematizing electrical phenomena. Within a context I specifically designed to broadly support students' translanguaging practices, I address these research questions:

1. How did emergent bilingual students leverage various linguistic resources in the service of describing or explaining electrical phenomena?
2. How did emergent bilingual students leverage gestures in the service of describing or explaining electrical phenomena?
3. As the instructor, how did my responses to students' use of their semiotic repertoires make this science learning environment a translanguaging space, or not?

Methods

This study leveraged a Design-Based Research (DBR) approach (Bell, 2004; Cobb, Confrey, et al., 2003), and took place in an out-of-school science learning program that centered on students problematizing electrical phenomena. The choice of DBR was informed by its affordances for systematically investigating the complexity of learning environments and developing learning theories. Specifically, a design-based research method allowed me to formulate and refine localized theories about how emergent bilingual students in the program learned about electrical phenomena, leveraged multiple semiotic resources when problematizing the phenomena they observed, and the necessary resources (e.g., materials, pedagogical, semiotic) to support their productive disciplinary engagement. Moreover, I relied on qualitative methodologies (Miles et al., 2013) to analyze video recordings, audio recordings, and student-produced artifacts to identify instances when learners brought into coordination multiple semiotic resources (e.g., linguistic resources, gestures) when problematizing the electrical phenomena they observed.

Context and Program Design

The program was a partnership between me (Enrique) and a public library system whose administrators were interested in hosting a sustained science-based program for elementary-aged multilingual children. I designed the program with the intent of creating opportunities for students to ask questions about and investigate phenomena related to the transmission and transformation of electrical energy in DC circuits; I was also the instructor implementing the learning activities. The program was offered three times throughout 2016 (Spring, Summer, Fall), free of cost to participants, at library branches that served immigrant families, and recruited 12 elementary-aged emergent bilingual students in total. I refined on the program through mini-cycles of iterations (Cobb, McClain, et al., 2003), where I assessed the students' learning and participation during a session in relation to what I had planned for and adjusted future activities; I also engaged in macro-cycles of iteration, where I analyzed students' learning and participation after the end of one iteration (e.g., spring) and fed those insights and understandings forward to modify the planned learning trajectory for the following iteration (e.g., summer). For this study, I focus on the implementation at Dexter[2] Public Library during the summer of 2016 (see Appendix A for a description of the sessions).

Understanding the transmission and transformation of energy in systems, such as electrical circuits, is an important part of elementary school physical sciences. And while there is research consensus on how elementary-aged students ideas about electric flow in circuits (e.g., Driver et al., 2000; Osborne, 1983; Peppler & Glosson, 2013), little has been written about these learners' understanding of electrical resistance. Most of the research on this concept has focused on offering resources for supporting high school and college-aged students to learn about electrical resistance (e.g., Driver et al., 2005; Mcdermott et al., 2000). One study that focuses on how students conceptualize electrical resistance (Engelhardt & Beichner, 2004) suggests that high school and college-aged "students did not understand that a resistor … has an inherent resistance based on its shape and the material from which it is made" (2004; p. 113).

This lacuna is also reflected in elementary-level science curricula and standards. Since the mid 1990s (National Research Council, 1996), elementary school physical sciences standards have emphasized the importance of building on students' intuitive ideas about how energy is transmitted and transformed within a system. Most recently, the Next Generation Science Standards (NGSS Lead States, 2013) suggests that fourth graders should have opportunities for answering questions like, "what is energy?" and "how is energy transferred?". Specifically, the NGSS proposes two performance expectations that guide students' learning about energy: 4-PS3-2, which asks students to consider the transmission of energy by electrical current; and 4-PS3-4, which asks students to create a device, such as an electrical circuit, which can convert energy from one type to another. Grades K-2 do not explicitly include energy in electrical circuits, and grade 3 only considers electrostatic phenomena. However, elementary-aged students have traditionally learned about electrical resistance in terms of conductors (e.g., metals) and insulators (e.g., non-metals), a binary distinction that implies that electrical energy can be either transmitted or not through a circuit, never regulated nor transformed (e.g., FOSS Kits). While the first-order distinction between conductors and insulators is productive, this heuristic has limited power for explaining and predicting what happens to the electrical energy as it moves through materials. Therefore, engaging in tasks that can support elementary-aged students to problematize electrical resistance in more nuanced ways how energy is transmitted and transformed within circuits. The program was designed to address this gap by creating opportunities for students to problematize how electric flow in circuits is affected by electrical resistance; developing their conceptual understandings through engaging in epistemic practices and building on the conceptual resources they brought to bear, such as using water flowing through a pipe as a productive analogy for electricity in a circuit.

The program design comprised eight (8) sessions in which students engaged with different activities for investigating phenomena related to electrical resistance (see Appendix A for an outline of the sessions); each session lasted approximately sixty (60) minutes. Overall, the program was divided into three major parts that were designed and structured to create a sequence of activities through which students progressively problematized important conceptual aspects of electrical resistance: (1) investigating electric flow through a circuit; (2) investigating properties of conductors and resistors; and (3) exploring how the geometry of conductors

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[2] All names used in this manuscript for places and students are pseudonyms

affected electrical resistance. When investigating electric flow through a circuit (Sessions 1-5), students built circuits with traditional tools (e.g., battery, wires, lamps) and explained how they thought electricity flowed through a circuit to light up a lamp. Additionally, students explored how electricity could also flow through lines of conductive ink, deepening their understanding of what objects electricity could flow through (or not). When investigating properties of conductors and resistors (Sessions 5-7), students drew circuits with conductive ink that included a gap where students could place common household items (e.g., screws, aluminium foil, cardboard, plastic), predicting and testing which items would complete the circuit and, thus, acted as conductors or insulators. After completing their investigations, students constructed a rule to predict and explain which kinds of materials allowed or impeded electricity to flow (i.e., intensive properties). Finally, when exploring how the geometry of conductors affected electrical resistance (Sessions 7-8), students engaged in a series of investigations to problematize how the geometry of resistors affected electric flow (i.e., extensive properties), intentionally varying the length and width of the lines of conductive ink to observe the changes on how much electricity flowed through the circuit. Session 8 was also an opportunity for students to co-construct a final model that would integrate their evidence on how an object's material and shape affected electric flow (i.e., electrical resistance).

Each session was guided by specific task and participant structures (Sandoval, 2014) that embodied the principles of Productive Disciplinary Engagement. At the start of each session, the whole-group began with me promoting *student authority* and collaborative meaning-making through prompting students to summarize the findings from the previous session as a way to lay the foundation for the question students investigated next. This framing time was followed by a brief period of *problematizing*, during which students predicted answers to the question and possible experimental observations. Since I was not committed to students sharing canonical explanations about their observations, these periods were an opportunity for me and other students to be *accountable to each other* by listening attentively and understanding each other's reasoning. The second part of the session consisted of students working in small groups (2-3 students per group), proposing an investigation plan to address the session's driving question, as well as collecting and *problematizing the electrical phenomena* they observed. As the instructor, my role was to support students as they planned, collected, and interpreted data, asking questions and encouraging discussion amongst teammates. The investigation materials I included in each session (e.g., wires, batteries, conductive ink) were intended to serve as *relevant material resources* that would support students' *problematizing* electrical phenomena. During the third and final stage of the session, in their small groups, students constructed mechanistic explanations for their observations, often creating graphical representations of the entities and processes involved. Students then shared their explanations with the whole group and engaged with each other's ideas, comparing each other's models in order to identify similarities and differences, questioning whether the models predicted and explained the phenomena they observed, and ultimately refining their ideas towards reaching a consensus; this was not always achieved. I facilitated these discussions through the use of Talk Moves (Michaels & O'Connor, 2012; see Appendix B). Throughout these engagements, students' multiple semiotic repertoires served as *relevant resources* they leveraged in order to experience productive disciplinary engagement. Finally, though I purposefully planned the activities *a priori*, I was also strongly committed to attend to students' own questions and interests about the phenomena they observed as I implemented the program. My responsive design intended to *give students authority to problematize their observations* and make them stakeholders in their investigations of electrical phenomena, rather than creating scenarios where students could act-as-if they were engaged (Engle, 2012). Therefore, as the program's designer and instructor, I related and grounded the program's activities and driving questions in students' observations and questions.

Participants

The Dexter library branch serves a neighborhood of predominantly African-American families and immigrant families from Latin America (e.g., Mexico), Sub-Saharan Africa (e.g., Ethiopia), and East Asia (e.g., Vietnam). The summer 2016 iteration of the program recruited ten (10) students who used the library services, spanning grades 1st through 5th; attendance varied throughout the program and not all children were present at every session. Most participating students identified as bilingual and represented a wide range of home languages. Four (4) of the 10 students consented to participate in the research and attended most of the program's sessions. These consenting students were the only ones who attended the program from Session 3 onwards; therefore, this study focuses on sessions 3 through 8. These students were: Yesenia, a Latina 4th grader, and her brother Elio who was in 2nd-grade, both of whom spoke Spanish and English; and Toben, a 4th-grade Nigerian-Japanese learner, and his sister Grace, who also was in 2nd grade, both of whom spoke English, some Japanese, and some Igbo (see Appendix A for a summary of student attendance). I regularly encouraged students to use communicative resources from their full repertoires. Implicitly and explicitly, English became the program's *lingua franca*.

Researcher Positionality

As it is important to consider the multiple cultural knowledge systems that I bring to the study, both as an educator and a researcher, here is an introduction to myself. I grew up in a Spanish-speaking country in South America, with English being an ever-present additional language both at home and school; I reached a normative version of bilingualism in my mid-teens. As a young adult, I also began developing fluency in French, German, and Japanese, but stopped after a year of instruction for each. I am also a Western-trained astrophysicist and speaking multiple languages was particularly helpful throughout my career as an observational cosmologist, given that it allowed me to learn alongside scientists and texts from different parts of the world. Despite the explicit and implicit value my society placed on becoming a polyglot, the sanctioned version of bi-/multilingualism was monoglossic in nature, a perspective that intends to keep linguistic systems self-contained and separate during use. This language ideology was most commonly instituted through exhorting children to learn English as an additional language, but deriding those who spoke *Spanglish* – juxtaposing passages of speech from Spanish and English within the same speech exchange (Martínez, 2010). Against this background, I developed a bilingual identity with monoglossic performance at its core that has characterized my languaging for much of my professional career. And, despite ascribing to García's liberatory efforts to desettle the political barriers that keep languages separate and unequal (e.g., Flores & García, 2013; García, 2009a; García & Sylvan, 2011; Otheguy et al., 2015), I still struggle with fluidly drawing on linguistic resources from multiple systems when communicating. This tension between my commitment and languaging practices shaped my pedagogy in ways that I will describe in further detail in the *Discussion* section of this article.

Data Collection

For this study, I collected data from two main streams: video recordings of classroom interactions and auxiliary audio recordings, and student-produced artifacts. I prioritized video data because they contained the most information on students' translanguaging practices (e.g., using multiple languages and/or gesturing) when investigating and discussing the electrical phenomena they observed. The video data were collected using two video cameras, whose positioning varied in order to capture learners' ideas and gesturing when interacting with one another across different types of activities. In total, more than 16 hours of video were collected throughout the eight sessions at Dexter during the summer of 2016; two hours came from Session 1 and Session 2, which included non-consenting students and were, therefore, not analyzed. In addition to video and audio recordings of the activities, I collected still images of the work learners produced while engaging in the investigations, such as written text on white boards, drawings, and even the experimental setups they designed for collecting data to address the sessions' driving questions. These student-produced artifacts allowed the analysis to explore learners' translanguaging practices across modalities (e.g., written, spoken) for sharing their reasoning. In total, 42 images of students' work were generated throughout the eight sessions at Dexter during the summer of 2016; five of those images were generated by non-consenting students and, therefore, were not analyzed.

Data Analysis

My approach to analyzing the collected data was qualitative in nature (Miles et al., 2013), specifically based on interactional analysis (Jordan & Henderson, 1995), centering on how the students and the instructor engaged in translanguaging practices through layering linguistic and non-linguistic resources (i.e., named languages, gestures). While I acknowledge that making meaning of the natural world is a social activity that relies on multiple modalities, my primary focus was on modalities that are often undervalued in research and practice, especially when leveraged by emergent bi-/multilingual learners in the service of co-constructing knowledge. To this end, I analyzed the 14 hours of video collected from the four consenting students during the Dexter Summer 2016 iteration, as well as artifacts students created using linguistic resources from different named languages and/or used when gesturing (see Figure 1 and Table 1).

The first step in the retrospective analysis was condensing the data (Miles et al., 2013) by creating content logs that summarized the video (and audio recordings when necessary). I created a content log for each session where I described the learners' meaning-making and their engagement in translanguaging practices. Each content log comprised video recordings from all the cameras used, as well as tape from the audio recordings when the video recordings had poor audio quality. The content logs first classified these data according to the overall task structure that was taking place (e.g., introduction of the investigation, collecting and interpreting evidence); these portions were then divided into 5-minute segments, each one describing the students' and instructor's participation and communication in the investigation. The second step in the analysis was to inductively generate categories according to the kind of activity students engaged in and coarsely classify them: (i) students problematize electrical phenomena; (ii) students organize the logistics of activity; or (iii) students socialize with each other. This activity-based heuristic was helpful for identifying instances when PDE could be taking place and to further analyze them. Using MS Excel, I coarsely tagged all episodes according to the linguistic (e.g., Spanish) and/or non-linguistic (e.g., gestures) resources students leveraged. Spoken English was the default tag, given its role as *lingua franca*.

Once the content logs were created and the segments within them coarsely classified by task structure, kind of activity, and communicative resources, the next step was to identify the episodes of students problematizing electrical phenomena. I identified and bounded relevant episodes by students engaging in one or multiple of the following disciplinary epistemic practices related to problematizing phenomena (Engle, 2012): (i) posing questions about electrical phenomena; (ii) collecting and/or interpreting evidence about electrical phenomena; (iii) constructing mechanistic models that included entities, activities, and/or initial and termination conditions (Russ et al., 2008); and (iv) collaboratively assessing the explanatory power of a mechanistic model based on available evidence, and refining the model to accommodate discrepancies. I then analyzed these episodes at a finer-grained level, defining a speaker's turn of communication as the unit of analysis and attending to the progression of speakers' thinking that was directly related to wondering about and/or explaining what was happening to the electricity as it moved through the circuit. Specifically, I categorized the different mechanistic models the students proposed to explain their observations about electricity flow and electrical resistance. As I identified the different mechanistic models, I inductively coded for the aspects of mechanisms students include in their explanations of what happened to the electrical energy in the circuit, particularly the intensive (e.g., composition) and extensive (e.g., length) properties electrical resistors.

Given my interests in understanding students' translanguaging practices while problematizing phenomena, I focused the analysis on translanguaging events (Alvarez, 2014): an analytical unit situated in local learning activities where participants (e.g., learners, instructors) leverage linguistic resources associated with two or more names languages (e.g., English, Spanish), and/or non-linguistic resources (e.g., gesturing) for collaborative meaning-making; Figure 1 and Table 1 represent an example of this kind of episode. The first step in isolating these events was to identify exchanges when students and/or I coordinated linguistic resources different named languages, either in spoken or written form. This analytical choice was rooted in theoretically framing linguistic resources associated with different named languages as representatives of the "ordered and categorized lexical and grammatical features" (Otheguy et al., 2015, p. 289) that comprise a person's linguistic repertoire. Therefore, in agreement with other researchers (e.g., Alvarez, 2014; Espinosa & Herrera, 2016; Flores & García, 2013; Poza, 2016), I determined that the co-occurrences of named languages in close temporal proximity indexed participants drawing on various linguistic resources from their full semiotic repertoires.

After identifying these exchanges, I quantified the number of co-occurrences during each 5-minute segment of video. The results from the coding allowed me to map when participants engaged in translanguaging through linguistic resources in each session, as well as the whole program, and helped me identify how common this type of translanguaging was.

Table 1: Transcript of Elio and Yesenia's discussion with writing on their whiteboard an explanation of what they thought the battery did in a circuit (Session 4)

Line	Speaker	Utterance (translation in English)	Actions
Start of activity: Instructor asks students to write their ideas on a white board			
1	Yesenia	Se está prendiendo porque… (it is turning on because…)	
2	Elio	La batería está haciendo energía para que prenda (the battery is making energy for [lamp] to turn on)	*((points to the circuit))*

3	Yesenia		*Writes on whiteboard:* The battery
4	Elio	Generates. Ponle generates (add generates)	
5	Yesenia	Eso es una palabra… (that is a word that…)	
6	Yesenia		*Writes on whiteboard:* generates energy but without
7	Elio	Generate es con silent E (Generates has a silent e)	
8	Yesenia	"The battery generates energy but without"	*Reading the white board*
9	Elio	¿But without qué? (But without what?)	
10	Yesenia		*Writes on whiteboard:* the battery the bulb won't light up
Change in activity: Yesenia and Elio read their white board for Toben and Grace			

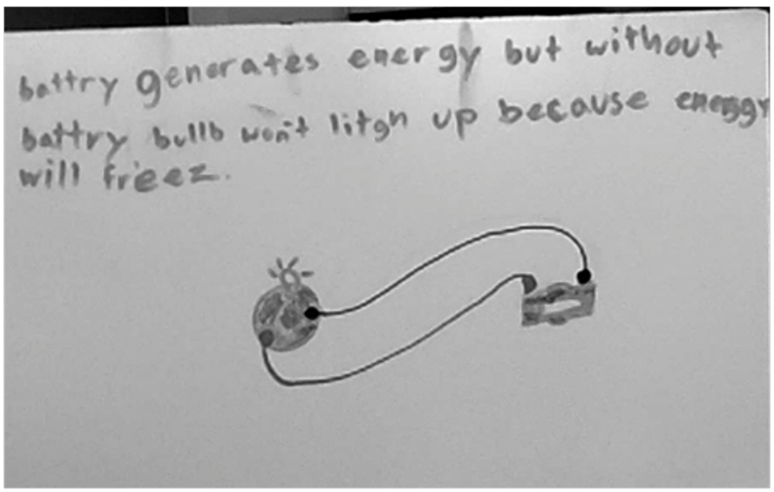


Figure 1: Elio and Yesenia's whiteboard with an explanation of what they thought the battery did in a circuit (Session 4)

Additionally, I focused my analysis on moments when learners and I were translanguaging through gestures, which I operationalized as: any body movement, specifically involving the hands and/or arms, which serves to describe an observation or present an explanation, with a clear beginning and end. Particularly, I drew on the work by David McNeill (McNeill, 1992, 2005), who developed a taxonomy of gestures to identify the kinds of gestures speakers rely on when engaging in different communicative acts (see Table 2). McNeill defined four main dimensions of gesture after observing speakers of different ages and different heritage languages, each with particular body motions and functions. *Deictic* gestures are specific hand movements used in concrete or abstract pointing that derive their meaning from the context in which the interlocutors communicate. *Iconic* gestures are hand/arm movements that bear a transparent, perceptual relation to the semantic content of speech, and/or concrete entities and events the speaker is referring to. *Metaphoric* gestures refer to a visual image, much like iconic gestures, but this image is related to an abstract concept, like a thought or electricity. Finally, *beats* are a form of gesture used for providing temporal and/or emphatic structure to utterances, and yet their form does not present any distinguishable meaning. I identified exchanges when participants leveraged gestures when problematizing electrical phenomena and used three dimensions of gesturing as deductive codes for characterizing learners' gestures (see Table 2 for definitions and examples); beats were excluded because they do not communicate propositional or topical content, both of which are integral to problematizing phenomena. After identifying these exchanges, I quantified how many of each type of gesture occurred during each 5-minute segment of video. Using the results from the coding, I created a graphical representation of when students used gestures when sharing their observations and reasoning, which helped me understand how frequently students gestured throughout the program.

Table 2: Dimensions of gestures as deductive codes, based on the work of McNeill (1992, 2005).

Dimension of Gesture	Sample of Coded Data
Deictic	"The energy comes through the wires ((touches one of the connected wires)) and then you put on the metal things and it would go right here ((touches where the wire is clamped to the lead of the lamp holder))."
Iconic	"If [the conductor is] fatter ((moves thumb and index fingers apart from each other)), more electricity can flow faster."
Metaphoric	"And the energy from the battery causes the whole thing to run ((moves hand in a circle above the complete circuit)) perfectly."

Findings

Throughout the program, students engaged in different kinds of translanguaging practices when problematizing electrical phenomena, and co-constructing knowledge with each other and the instructor; some of these were spontaneously initiated by students and others were in response to the instructor's pedagogy. Here, I present findings from the analysis on the linguistic resources and gesturing students leveraged when problematizing electrical phenomena through co-constructing mechanistic models. Finally, I analyze the instructor's translanguaging practices that seemed to create a space for students' own translanguaging practices through linguistic resources, looking for patterns across the program and unpacking the last session.

Students engaging in translanguaging practices: leveraging multiple linguistic resources

Throughout the program, there were 91 translanguaging events where students leveraged linguistic and non-linguistic semiotic resources to problematize electrical phenomena (see Table 3). Yesenia and Elio were the only two students who used linguistic resources associated with named languages; Toben and Grace engaged in translanguaging only through gestures.

Table 3: Summary of exchanges where students problematized electrical phenomena while engaging in translanguaging practices through linguistic and non-linguistic semiotic resources.

Session	**Gestural Events**		**Linguistic Sampling Events**	
	Toben & Grace	*Yesenia & Elio*	*Toben & Grace*	*Yesenia & Elio*
3	12	(Absent)	0	(Absent)
4	4	8	0	9
5	(Absent)	3	(Absent)	6
6	(Absent)	6	(Absent)	7
7	3	5	0	2
8	(Absent)	16	(Absent)	10
Sub-total	57 gestural events		34 linguistic sampling events	
Total	91 translanguaging events			

Yesenia and Elio used linguistic resources from English and Spanish when participating in the sessions' activities, as they collaborated with each other or engaged with the instructor (see Figure 2). The sustained presence of translanguaging practices throughout the program indicates that Yesenia and Elio had opportunities to draw from multiple linguistic resources as they explored and made sense of electrical phenomena, suggesting the learning environment became a translanguaging space for them. However, as I will discuss below, the learning environment may not have created similar conditions to support Toben and Grace's translanguaging through multiple linguistic resources (see Table 3).

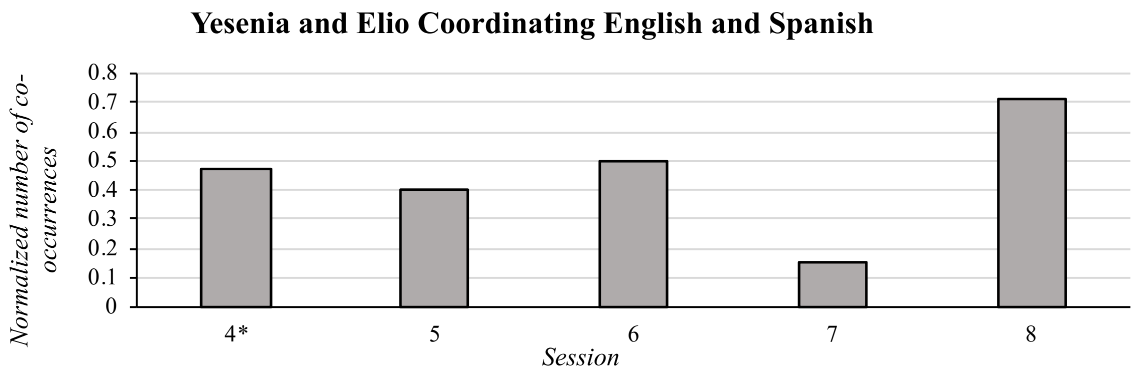


Figure 2: Times that Yesenia and Elio coordinated English and Spanish, indexing translanguaging through linguistic resources. The total number of gestures students enacted was normalized by the number of segments in each session, to provide a more accurate comparison. *Yesenia and Elio arrived early and investigated a wire loop puzzle toy (simple circuit) they brought, before Toben and Grace arrived.

Translanguaging through leveraging multiple linguistic resources played a central role for how Yesenia and Elio shared their ideas about electrical phenomena. The example I present below comes from the last session of the program (Session 8), when students used gel pens that contained conductive ink (Russo et al., 2011) to draw circuits that worked just the same as wired circuits. Specifically, students were investigating how the thickness of line of conductive ink regulated how much energy flowed through the circuit, in other words, how the conductors' electrical resistance depended on their width. Yesenia drew a few circuits with different thicknesses and compared how the lamp's brightness changed as a function of the lines' thickness, observing that the lamp shone dimmer when connected to the thinner circuit than when connected to the thicker circuit. The instructor noticed the difference in the lamp's brightness, and the following exchange ensued:

Table 4: Yesenia explains how a line's thickness regulates electric flow through the circuit (Session 8)

Lines	Speaker	Utterance (translation in English)	Actions
1	Instructor	A ver, Yesenia. Show me. ¿Qué estás pensando? (Let's see, Yesenia. Show me. What are you thinking?)	
2	Yesenia	La energía puede ir más rápido en este lado (The energy can go faster on [thick conductor])	*((Points to thick conductor))*
3	Yesenia	que en este lado… (than on this side [thin conductor])	*((Points to thin conductor))*

4	Yesenia	porque está muy chiquito y hay menos espacio para que la electricidad vaya, y aquí hay más espacio (because it [thin conductor] is very small and there is less space for the electricity to go, and here [thick conductor] there is more space.)	*((Points to thick conductor))*
5	Yesenia	Entonces está más fácil que vaya acá (So, it is easier for it to go here [thick conductor])	*((Points to thick conductor))*
6	Yesenia	pero a veces se atora aquí (but sometimes it gets stuck here [thin conductor])	*((Points to thin conductor))*
7	Yesenia	y no puede volver a la batería. (and it can't go back to the battery)	
8	Instructor	O sea, puede pasar por uno (So, it can through one)	*((Points to thick conductor))*
9	Instructor	but it can't go through the other one, kind of a thing.	*((Points to thin conductor))*
10	Instructor	How come – what do you think was happening when you had these two big ones?	
11	Yesenia	It would be easier and it [electricity] could go faster.	
12	Instructor	It could go faster both ways? And what about this one, this thin one?	
13	Yesenia	It would go slower and it might – might take a longer time to get through. Or it could – it would be harder for the energy to go through.	

The instructor began by asking Yesenia to explain her observations, in Spanish, "¿Qué estás pensando?" (Table 4, line 1). Yesenia continued through using resources associated with Spanish and proceeded to present her reasoning about how the lines' thickness affected how much electricity was flowing through, stating that thinner lines would make it harder for electricity to move through because it could get stuck and, thus, interrupt the electric flow; whereas, thicker lines provided the electricity with plenty of space to move through, without losing speed (Table 4, lines 2-7). Yesenia constructed a rich explanation that included a sequencing of events and described in detail how the lines' thickness determined how much space was available for the electricity to move through the circuit at different speeds, and whether it would get stuck along the way. Yesenia's was a mechanistic account (Russ et al., 2008) of how the conditions of the system (i.e., lines' thickness) determined the activities (i.e., flow) the main entity (i.e., electricity) engaged in and gave rise to the phenomena she was observing (i.e., differences in the lamp's brightness). Yesenia's explanation was richer and more complete than underlying and/or relational causal models (Perkins & Grotzer, 2005), such as "thin lines make the lamp dimmer", given that she identified salient processes and their sequencing in order to explain what she observed.

The instructor proceeded to summarize and clarify Yesenia's reasoning, using linguistic resources associated with Spanish and English, respectively: the electricity could move through the thick line (Table 4, line 8), but not the thin one (Table 4, line 9). Yesenia then used linguistic resources associated with English as she stated that the thicker line would make it easier for the electricity to flow through, allowing it to move faster through the circuit (Table 4, line 11); the thinner lines would make it harder and, therefore, it would take longer for the electricity to move through (Table 4, line 13). This portion of the exchange stands out because Yesenia's explanation using linguistic resources associated with English was similar and as rich as the explanation she presented when using linguistic resources associated with Spanish. The similarity between Yesenia's explanation across named languages suggests that she was certain of her understanding of what was happening to the electricity in the circuit and skillfully drew from her full linguistic repertoire when constructing and sharing her explanation.

Despite the similarities between the two explanations, the one Yesenia presented using Spanish resources points to a richer layer of understand than what is readily available in her English-based explanation. Specifically, Yesenia chose specific verbs from each names language when describing the resistance that the electricity experienced in each conductor, i.e., "to be" from English and "ser/estar" from Spanish. Technically, these two verbs are the translation of each other, but interlocutors can conjugate them differently to denote specific states of being. Particularly, the Spanish version of the verb in the form "estar" is reserved for temporary states of being, such as emotions, as well as locations; the form "ser" is used to index (quasi-)permanent states of being, such as kinship. For the English verb "to be" to do this kind of differentiation between states of being, the interlocutor would need to add a series of modifiers, such as "currently" or "permanently," making communication less succinct and perhaps more complicated for a person who is developing their English fluency. Taking these grammatical differences into account, when Yesenia said "está más fácil que vaya acá" (Table 4, line 5), Yesenia's choice to use the form "estar" indicates that she made sense of what was happening to the electricity to be a conditional state: the resistance the electricity experienced in the conductor was a function of its geometry and altering those conditions changes the result (i.e., the lamp's brightness). In other words, through using "está" in her Spanish-based explanation, rather than "es", Yesenia indexes the conductor's resistance as a variable state, rather than a permanent one.

Having access to her full linguistic repertoire gave Yesenia the tools for making sense of and talking about the nature of electricity in ways that may not have been accessible to her had she been obligated to keep the resources from both languages separate. Finally, Yesenia used a combination of speech and gestures when sharing her reasoning about how the lines' thickness made a difference (see Table 4, *Actions*), particularly pointing to the different lines. As the next case will illustrate further, pointing can serve to disambiguate speech (Blackledge & Creese, 2017; Roth, 1996, 2001), highlighting the specific physical elements others should attend to.

Students engaging in translanguaging practices: leveraging gestures

Students also resorted to gesturing when describing their observations and presenting their reasoning about electrical phenomena. Based on the coding of exchanges between students, and between students and the instructor, it became clear that gesturing was ubiquitous throughout the program (see Figure 3). Attending to the corporeal dimension of translanguaging, which considers embodied communication as crucial for collaborative meaning making, the sustained presence of multiple dimensions of gesturing suggests that the learning environment acted as a translanguaging space where students problematized electrical phenomena through leveraging their broader semiotic repertoires. Figure 3 shows that students did not use all dimensions of gesturing in each session; perhaps the nature of the activities shaped differential uses of gestures.

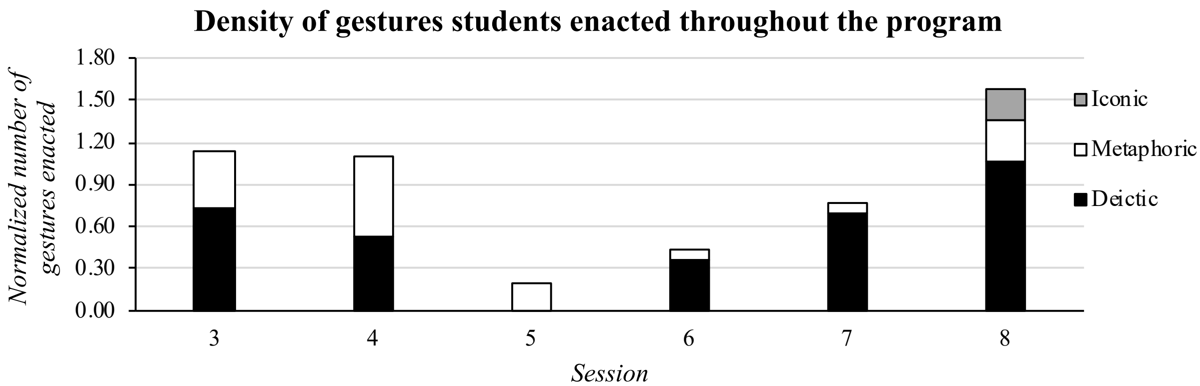
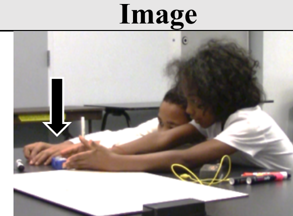
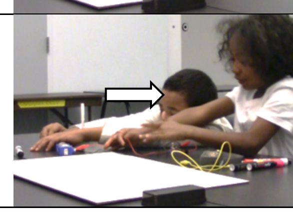
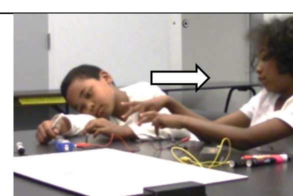
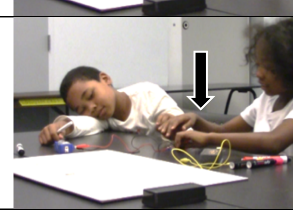
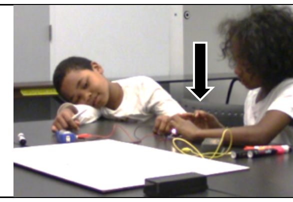
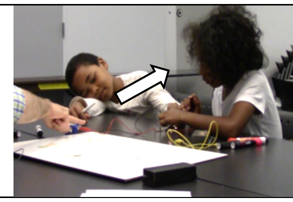
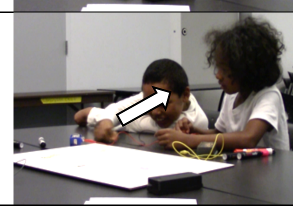
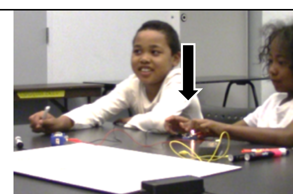
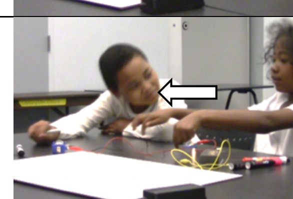
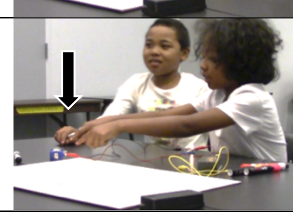


Figure 3: Main three dimensions of gesturing (deictic, iconic, and metaphoric) that students used when describing their observations and sharing their explanations about electrical phenomena. The total number of gestures students enacted was normalized by the number of segments in each session, to provide a more accurate comparison.

To further illustrate how students used different dimensions of gesturing throughout the program, I analyze Grace's gestures when sharing her account for how electricity flowed through a circuit. This episode happened during Session 3, when Toben and Grace (the only students in attendance) constructed a model for electric flow. The instructor asked Grace how she thought the electricity moved through the circuit, prompting the following contribution:

Line	Time	Speaker	Utterances ((gestures))	Image
1	00:24:15	Grace:	If you connect them right here ((touches each side of the battery))	
2	00:24:17	Grace:	it [electricity] bounces off here and it [electricity] goes ((tracing wires with fingers))	
Graces whispers something inaudible				
3	00:24:30	Grace:	It [electricity] goes all the way ((tracing wires with fingers))	
4	00:24:32	Grace:	over here ((touches lamp))	

5	00:24:37	Grace:	and then they're the same ((connects wire to lamp and lights it up))	
6	00:24:39	Instructor:	And then they meet there [the battery]?	
7	00:24:40	Grace:	Yes!	
8	00:24:41	Instructor:	So, you're saying it's coming out from here [black wire] and here [red wire] at the same time, and then they travel, and then they meet at the light bulb.	
9	00:24:46	Grace:	Yeah.	
10	00:24:47	Instructor:	Do you agree with that, Toben? Do you think it's going through both wires at the same time, or do you think it goes a different way?	
11	00:24:55	Toben:	This one [red wire] goes first	
12	00:24:57	Toben:	And this one [black wire] goes second	
13	00:25:03	Toben:	Coz if they go both, it might not make it um - make the light bulb not turn on and it might get messed up.	
14	00:25:16	Grace:	I think so because ((points to lamp))	
15	00:25:17	Grace:	it keeps on going ((traces wires with fingers, towards the battery))	
16	00:25:18	Grace:	like that ((points to the battery))	

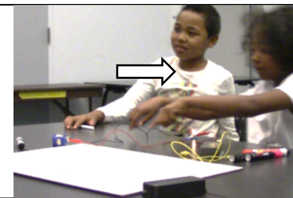
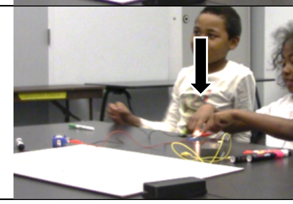
17	00:25:20	Grace:	((traces wires with fingers))	
18	00:25:20	Grace:	and it meets here ((points to the lamp))	

Figure 4: Grace describes how she thinks electricity flows through a circuit. (Session 3)
(White arrows represent hand motion and its direction; Black arrows represent hands are stationary)

Through combining gestures and speech, Grace described her initial model of how electricity moved from the battery to the lamp. The process Grace described first required that the wires were connected to the battery, which she alluded to by touching each side of the battery (deictic gesture) as she spoke (Figure 4, line 1). Once the wires were connected, Grace traced each wire with a finger, moving her hands away from the battery and towards the lamp (Figure 4, lines 2-3); through these metaphoric gestures, Grace illustrated the invisible and abstract concept of electric flow, specifically how each wire carried electricity independently and simultaneously. Her next claim was that the two streams of electricity met at the lamp, which she said as she touched the lamp (deictic gesture) and connected the wires and it up (Figure 4, lines 4-5).

When the instructor asked Toben what he thought of Grace's claim (Figure 4, line 10), he countered that each wire would carry electricity at different times: electricity moved through the red wire first, tracing it with his finger (Figure 4, line 11), and then traveled through the black wire, also tracing his finger over it (Figure 4, line 12). Through these two metaphoric gestures, Toben illustrated how he thought electricity flowed from the battery, through each wire at different times, and towards the light bulb. Toben further added that if electricity were to travel simultaneously through each wire, as Grace's model suggested, the circuit would get "messed up" (Figure 4, line 13). In response, Grace pointed to the lamp (deictic gesture), signaling the physical and temporal beginning in this recursive process (Figure 4, line 14). From the lamp, Grace traced each wire with her finger, moving her hands away from the lamp and towards the battery (metaphoric gesture), until she reached and pointed to the battery (deictic gesture) (Figure 4, lines 15-16). Through these hand motions, Grace represented again how the electricity moved simultaneously through each wire and returned to the battery. Finally, starting from the battery, Grace traced each wire with her hands once more (Figure 4, line 17), ending at the lamp, which Grace pointed to (deictic gesture) when stating that the electricity from each wire met there (Figure 4, line 18). Grace addressed Toben's concern about the electricity from each wire reaching the lamp simultaneously and, to further bolster her claim, Grace added, "If it went one at the time it would go like this [red wire] it would turn on, and then the other one [black wire] and it would turn on. That's why I think it goes at the same time" (Session 3).

In effect, Grace described a detailed mechanistic account (Russ et al., 2008) that resembled the "Clashing Currents" model of electricity moving through a circuit (Osborne, 1983; Peppler & Glosson, 2013). By marshalling speech and gestures, Grace highlighted the salient entities (e.g., electricity, wires), described the sequencing of events of how the lamp turned on, and illustrated the abstract concept of electric flow. Moreover, Grace was able to construct and share an argument that countered Toben's counterclaim, making explicit why his alternating model was not consistent with their observations of the lamp. To illustrate the function of her gestures, I isolated Grace's speech from the gestures she enacted while speaking (see Table 5).

Table 5: Comparing the meaning that can be extracted from Grace's contributions without and with gestures

Lines	Grace's Speech	Inferred Model: Speech + Gesturing
1	Grace: If you connect them	Wires need to be connected at each side of the battery.
2-4	Grace: it [electricity] bounces off here and it [electricity] goes … it [electricity] goes all the way … over here.	Electricity flows from the battery to the lamp through each wire separately.
5	Grace: and then they're the same	Each wire carries the same amount of electricity.
14-18	Grace: I think so because … it keeps on going … like that … and it meets here.	Electricity recursively moves from the battery to the lamp, through the wires, and back.

It is difficult to do a one-to-one correspondence between Grace's statements and her model of electric flow without having access to her gestures, observing how she is moving her hands while talking in relation to the tangible tools in front of her. Taking the last five utterances as an example (Table 5, lines 14-18), Grace refers to the electricity "going on … like that," but without access to her gesturing we cannot know what exactly "like that" means. Similarly, Grace states "it meets here," which is difficult to understand through her speech alone because the deictic term "here" is imprecise and can only be disambiguated through pointing. This suggests that leveraging multiple resources from a larger semiotic repertoire supported Grace sharing her thinking about how electricity flowed through the circuit she was exploring.

Instructors' translanguaging moves that supported students' own translanguaging practices

While the learning environment served as a translanguaging space, where students could leverage multiple resources from their full semiotic repertoires, the analysis thus far shows that these opportunities were not available to all students, during all sessions. Therefore, it is important to understand how and when the instructor's pedagogical moves made the program a translanguaging space. Mapping the occurrence of students' translanguaging throughout the program reveals the differential opportunities for students to use various resources from their semiotic repertoires. Focusing on students' gesturing, all students were able to deploy these non-linguistic resources when sharing their ideas with others (Figure 3). On the other hand, Table 2 and Figure 5 reveal that not all students had opportunities for translanguaging through using multiple linguistic resources, in particular those associated with various named languages. In particular, Session 7 had the lowest number of translanguaging exchanges using linguistic resources (i.e., co-occurrences of named languages) of the program (n = 2). While each session was different, what stands out the most about this session is that all four students were present at the same time: Yesenia and Elio, who shared resources associated with English and Spanish with the instructor; and Toben and Grace, who only shared resources associated with English with all participants. To better understand translanguaging under different conditions, I differentiated between sessions with all students in attendance, and sessions where only Yesenia and Elio were present. The results are illustrated in the two figures below (Figure 5 and Figure 6).

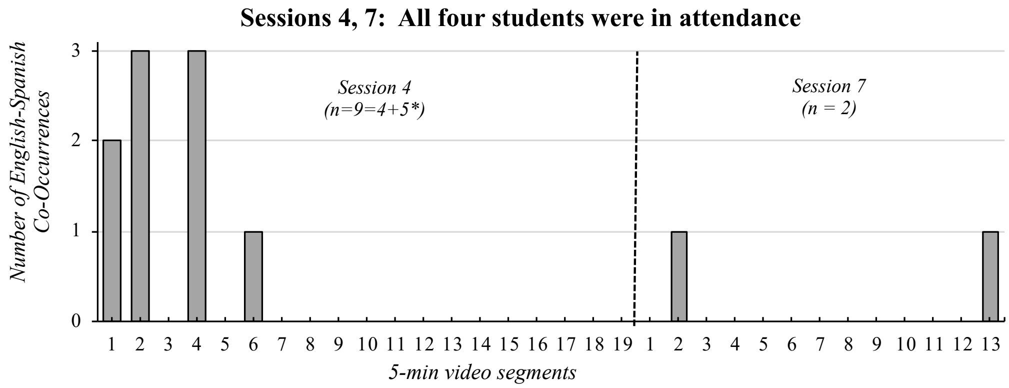


Figure 5: Number of exchanges with English-Spanish co-occurrences in sessions where all four students were in attendance. *Segments 1 and 2 from Session 4 occurred with just Yesenia and Elio in the room, before Toben and Grace arrived.

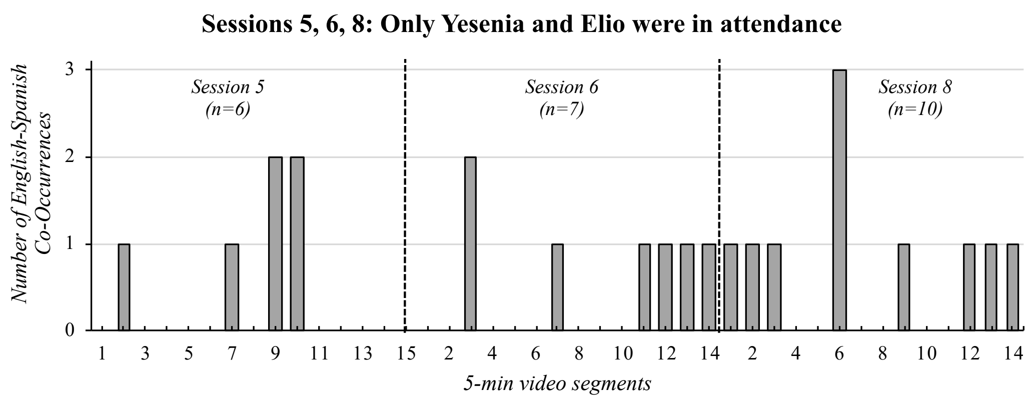


Figure 6: Number of exchanges with English-Spanish co-occurrences in sessions where only Yesenia and Elio were in attendance. *Segments 1–6 from Session 5 included a monolingual English-speaking student who left the program midway through segment 6, leaving Yesenia and Elio as the only students.

Figure 5 shows that during the Sessions 4 and 7, when all four students were present, there were eleven exchanges when Yesenia and Elio coordinated linguistic resources associated with English and Spanish across the two sessions; roughly, 45% of those 11 exchanges happened before Toben and Grace arrived at the session. However, as shown in Figure 6, during Sessions 5, 6, and 8, when Yesenia and Elio were the only students in attendance, the number of exchanges with co-occurrences of Spanish and English increased to 23 across the three sessions. In other words, when all participants shared similar linguistic resources (e.g., Sessions 5, 6, and 8), the number of exchanges with English-Spanish co-occurrences doubled, compared to the sessions when not all linguistic resources were shared among the participants (e.g., Session 4 and 7). The increase in the number of exchanges that included co-occurrences of named languages suggests that the availability of opportunities for translanguaging through leveraging linguistic resources associated with named languages depended on who was present. This increase could be partly due to Yesenia and Elio being aware of and responsive to their peers' linguistic repertoires, leveraging linguistic resources associated with Spanish and English when working together (e.g., Figure 5, Session 4: segment 4), while acknowledging that they needed to share their thinking with Toben and Grace in English. Evidence also suggests the instructor's pedagogical moves had an effect.

To better understand how different contextual factors supported translanguaging, I identified and analyzed the moments when students and the instructor leveraged different linguistic resources during the last session of the program (Session 8), which had the most exchanges with English-Spanish co-occurrences (n = 10). As mentioned before, during this session Yesenia and Elio were investigating how the width of the conductive lines' thickness determined its electrical resistance and, consequently, how much electricity flowed through the circuit. The resulting timeline is shown in Figure 7, which reveals features about how the students and the instructor used linguistic resources. First, the graphical timeline shows the fluidity with which all participants used Spanish and English, leveraging linguistic resources associated with both named languages multiple times throughout the session. Table 4 (analyzed above) illustrates what this type of translanguaging looked like in practice: Yesenia and the instructor leveraged both linguistic and non-linguistic resources when discussing how thinner conductive lines decreased the electric flow through the circuit (Figure 7, 36:00-37:00). At the same time, the extended periods of using resources from only one named language suggest that Yesenia and Elio were adept at performing a monoglossic version of bilingualism (i.e., multilingual learners have multiple separate whole languages that are kept segregated and used independently), were the learning context to expect it from them.

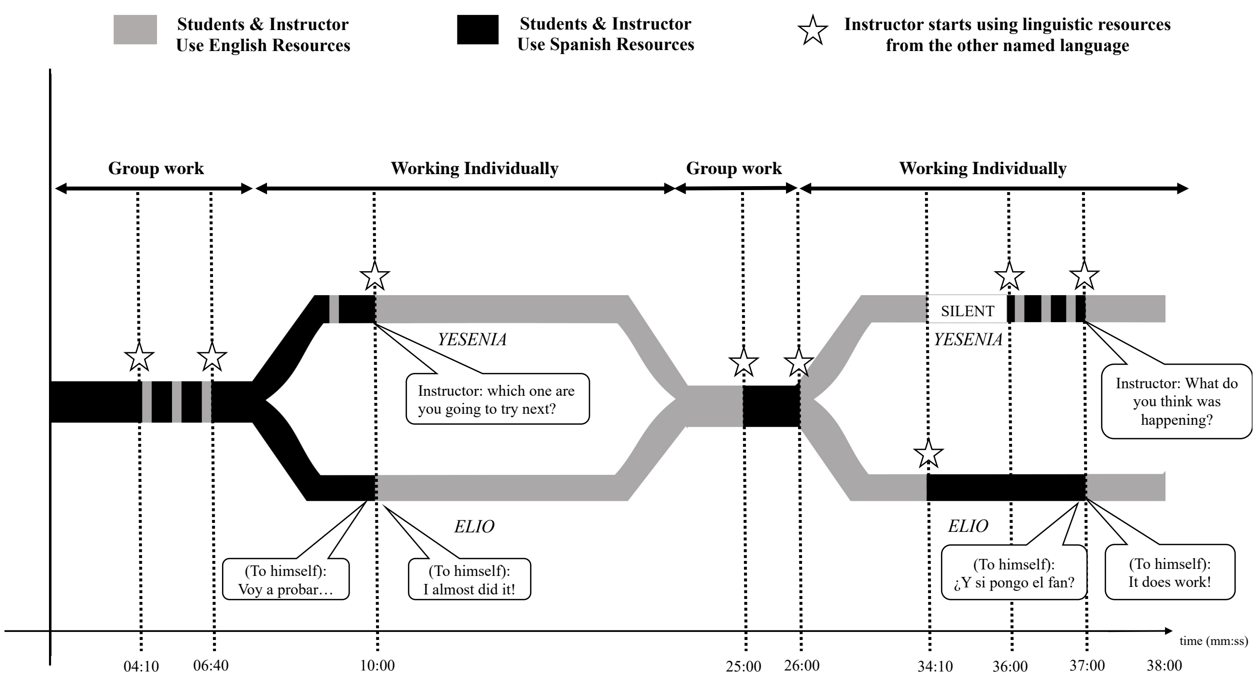


Figure 7: Mapping when the students and the instructor used linguistic resources from English and Spanish during the last session of the program.

The second feature this timeline makes explicit is that the instructor seemed to set the linguistic expectations and conditions of the learning environment, which students followed.

These conditions are evinced by the changes in the named language used by the speakers before and after the white stars on the graph: as soon as the instructor used resources from Spanish, Yesenia and Elio followed suit; the same happened with resources from English. For example, students continued using resources from Spanish as they transitioned from one task format to another (Figure 7, 6:40) and, at the 10th minute, the instructor asked Yesenia, "which line are you going to start with?", changing the named language and requesting details about her investigation. Yesenia responded, "the super fat one", referring to the thickest line she could draw. For the next 15 minutes Yesenia, the instructor, and Elio communicated using linguistic resources associated with English. This monolingual period came to an end when the instructor, once again, used resources from Spanish, which Yesenia and Elio accommodated to and used Spanish for the next minute, until the instructor started using resources from English again. Finally, when the instructor used both Spanish and English, as exemplified by the striped moments (Figure 7, 4:10-6:40, 36:00-37:00), students also used Spanish and English for sharing their ideas about electric flow. Thus, the way students followed the instructor's linguistic lead suggests that they were responding to a shift in the linguistic expectations set by the instructor.

The instructor's influence on setting linguistic expectations was not limited to the student he interacted with; it impacted all who were present. On several occasions, the instructor was interacting with one of the students, he used resources associated with a different named language, and the student sitting across the table also began using resources from the same named language. For example, when the instructor asked Yesenia a question in English (Figure 7, 10:00), Elio, who was sitting across the table and talking to himself using resources from Spanish as he investigated the circuit, immediately began using resources from English, despite not being addressed by the instructor. This happened again in the 37th minute of the session, this time moving from Spanish to English resources when he heard the instructor speak English. This at-a-distance effect supports the context-dependent nature of opportunities for translanguaging.

Discussion and Implications

In this study, I identified and described the translanguaging practices a group of four emergent bilingual students engaged in when problematizing electrical phenomena. Specifically, students shared their observations and reasoning from their investigations through leveraging linguistic resources associated with different named languages (e.g., Spanish, English). Students also leveraged other resources from their broader semiotic repertoires, particularly multiple dimensions of gesturing, when constructing and sharing their models. These two findings suggest that, under specific circumstances, the learning environment acted a translanguaging space where students problematized and co-constructed knowledge about electrical phenomena without adhering to arbitrary boundaries between semiotic resources; often, students followed the implicit or explicit communicative expectations I (as the instructor) set. After discussing these findings, I reflect on how my positionality might have influenced my pedagogy, offer pedagogical implications for science education, and outline future research.

Leveraging multiple semiotic resources when problematizing electrical phenomena

Before delving into students translanguaging practices, it is important to highlight the understanding of electrical phenomena they demonstrated during the program. With regards to the transmission of electrical energy through a circuit, students shared various mechanistic models for how they thought electricity moved from the battery to the lightbulb, though only Grace and Toben's were shared here. And while their models of electric flow were not canonically correct, Toben and Grace productively engaged in epistemic practices for constructing models that tried to represent their observations, as well as evaluating each other's models based on their interpretations of the time it takes for electricity to move through the circuit (see Figure 4). With regards to students' understanding of electrical resistance, Yesenia's model attended to the extensive properties of resistors, particularly how altering the geometry of a resistor affects electric flow in a circuit. Specifically, Yesenia proposed a model that described in detail how the lines' thickness determined how much space was available for the electricity to move through the circuit at different speeds, and whether it would get stuck along the way. Students' engagement with electrical phenomena described here could be considered disciplinary, both in terms of the practices students engaged in (e.g., asking questions, collecting and interpreting observations, and constructing evidence-based models about electric flow) and the deep questions about physics they were asking (e.g., transmission and transformation of electrical energy in circuits). Their engagement could also be considered productive, particularly given the changes they made to their models of electric flow as they gathered more evidence through novel investigations (e.g., leaving the insulator/conductor binary behind and proposing a model of electric flow that accounted for extensive properties of resistors). Thus, this study's findings can serve as case studies for the conceptual understanding elementary-aged students can develop about electrical resistance, which are not captured by the current science education literature. Moreover, students' thoughts and explanatory models evince the complexity with which elementary-aged students can problematize electrical phenomena, provided that the learning environment is designed to support their productive disciplinary engagement. The contributions to both the learning and the means to support it highlight the advantages a Design-Based Research (DBR) approach has understanding complex learning and theory-building.

With regards to students' discursive practices, the study's first two findings describe the range of semiotic resources students drew upon when problematizing specific electrical phenomena. Notably, Yesenia and Elio were adept at engaging in translanguaging practices through leveraging linguistic resources associated with multiple named languages, namely English and Spanish (see Table 3 and Figure 2). Having at their disposition linguistic resources associated with two named languages to draw from proved useful for Yesenia and Elio in this learning environment, especially when one system may have had limited communicative power, or the environment required so. It is not difficult to imagine how Yesenia's opportunities for coordinating multiple linguistic resources into a complex explanatory model could have been foreclosed had she been in a learning environment with restrictive language policies and practices. Moreover, if our theories and commitments to equitable science education for emergent bi-/multilingual learners foreground homogeneity (i.e., converging the semiotic resources youths bring to learning environments towards English-based disciplinary discourses), then we run the risk of misrecognizing the conceptual sophistication in Yesenia's model that included linguistic resources from both Spanish and English. A theoretical and empirical approach rooted in inviting and leveraging heterogeneity, such as translanguaging, instead gives researchers and educators an equitable lens through which to identify, value, and understand the communicative practices emergent bi-/multilingual students develop and/or acquire when making meaning of the natural world.

Drawing on multiple dimensions of gesturing was an additional translanguaging practice that all students leveraged when problematizing electrical phenomena, ubiquitous throughout the program (see Figure 3). Gestures, particularly when combined with speech, were productive for students to make their ideas more intelligible to their peers and instructor, especially when referring to invisible process, like electric flow; this is consistent with what other science education researchers reported (Roth, 1996, 2001; Ünsal et al., 2018). For example, Grace and Toben presented different models for how they thought electricity flowed through a wired circuit, both using gestures to illustrate the path electricity traveled and sequencing of events (Figure 4). Without resorting to words like "simultaneously" or "negating," Grace and Toben engaged in the kinds of productive epistemic practices that associated with (multimodal) modeling: presenting, evaluating, and countering their respective mechanistic models of electric flow, through using accessible verbs and multiple kinds of gestures (e.g., pointing and tracking). These findings are a positive example of why the "corporeal dimension of translanguaging" (Blackledge & Creese, 2017) is crucial for our theories and analyses of what equitable science education rooted in heterogeneity looks like for emergent bi-/multilingual learners. Specifically, if our theories and research designs are unable to recognize or are quick to dismiss the multimodal and multisensory nature of language (Blackledge & Creese, 2020; Li, 2018), then we run the risk of reifying the kinds semiotic power dynamics and hierarchies that disenfranchise bi-/multilingual speakers from fully participating in meaning-making. Moreover, a logocentric approach to teaching and learning may not only (inadvertently) position students as deficient (Grapin, 2019), it may also reify ableist notions about what forms of communication are recognized and accepted as disciplinary (see De Meulder et al., 2019; and Kusters & De Meulder, 2019, for an in-depth analysis of the embodied translanguaging practices of deaf and/or hard-of-hearing interlocutors). While it may be reasonable to expect students to eventually leave their gestures behind for more specific nouns or verbs to describe their observations and conjectures about natural phenomena, we must always ask ourselves: whose interests are being served by moving towards homogeneity?

Resources associated with named languages and gestures are only some of the various semiotic resources that can support meaning-making about the natural and designed worlds. Scientists draw on a wide range of communicative resources when questioning, investigating, understanding, and communicating about natural phenomena (e.g., Ochs et al., 1994). Therefore, is important to remind ourselves that scientists and learners engage in a broad range of modalities when constructing knowledge about the natural world. Because of this multimodal nature of scientific meaning-making, then, it is important to stave off "settled" (Bang et al., 2012) discursive ideologies and practices that unjustly narrow the gamut of semiotic resources bi-/multilingual learners can leverage. In this study, I have highlighted how two kinds of semiotic resources (i.e., named languages and gestures), which are often undervalued or even prohibited for emergent bilingual learners to use, supported meaning-making. Future research must account for how other modalities (e.g., online simulations) support student learning.

When did the learning environment act as a translanguaging space?

These four students coordinated multiple resources from their broader semiotic repertoires as they were problematizing electrical phenomena. The question of when the learning environment acted as a translanguaging space, however, does not have a straightforward answer. This study was guided by Li's definition of a translanguaging space as one where bi-/multilingual students can bring "together different dimensions of their personal history, experience and environment, their attitude, belief and ideology, their cognitive and physical capacity into one coordinated and meaningful performance" (Li, 2011, p. 1223). From this perspective, the learning environment acted as translanguaging space, as it afforded Yesenia, Elio, Grace, and Toben opportunities to layer linguistic and non-linguistic semiotic resources into a "coordinated and meaningful performance" when collaboratively problematizing electrical phenomena; this assertion is especially true when focusing on the multiple dimensions of gesturing students enacted throughout the program (see Figure 3). This first-order analysis, however, is not sufficient for describing the complexity of when, why, and for whom the environment acted as a translanguaging space.

As the analyses show, Toben and Grace engaged in translanguaging through using multiple dimensions of gestures, but not through linguistic resources from multiple named languages. From this perspective, the environment provided a constrained range of possible translanguaging practices to engage in when problematizing electrical phenomena. It is possible that because Toben, Grace, and I (the instructor) only shared linguistic resources associated with English, these students' possibilities for translanguaging through other linguistic resources might have been limited. And while Toben and Grace still had opportunities to engage in translanguaging through leveraging gestures, it is important to interrogate what opportunities for engaging in epistemic practices through translanguaging practices might have been missed. This partial overlap in semiotic repertoires, and its consequences for students' translanguaging, pushes me to wonder how to best design learning environments to act as translanguaging spaces when educators' and students' linguistic repertoires share resources from only one named language. Is it sufficient for educators to encourage students with similar linguistic repertoires to leverage those resources with each other, while they themselves do not leverage resources from those languages? While crucial, the data from Toben and Grace may tell us that it is not enough.

The findings suggest that I set the linguistic expectations throughout the program that students closely followed. Specifically, when the participants only shared linguistic resources associated with one named language (i.e., English), there were less opportunities for students to translanguage through leveraging linguistic resources (see Figure 4); when the linguistic repertoires of students and instructor had a greater overlap, more opportunities for translanguaging through coordinating different linguistic systems emerged (see Figure 5). The effect of my pedagogical moves on students' translanguaging was evident in much more detail through the analysis of the last session of the program. As the group problematized how a conductor's width affected its electrical resistance, Yesenia and Elio imitated my speech patterns and how I layered (or not) resources from different linguistic systems; this pattern is captured by long periods of monoglossic bilingualism and the intermittent coordination of linguistic resources associated with English and Spanish (see Figure 7). These findings resemble the ones reported in Stevenson's research (Stevenson, 2013, 2015), where the students' speech accommodated the named language their teacher and peers used during science lessons. Moreover, these findings highlight the key role educators play in creating translanguaging spaces where students can use their full semiotic repertoire for learning (García & Kleyn, 2016).

Wrestling with my positionality, bilingual identity, and translanguaging practices

Reflecting on the differential affordances for engaging in translanguaging led me to consider how, as the instructor, my own communicative positionality might have shaped the learning environment. As stated above, my semiotic repertoire includes linguistic resources associated with English and Spanish, although that did not preclude me from experiencing tensions about how and when to support students' translanguaging. As part of my struggles with fluidly drawing on linguistic resources from multiple systems when communicating, I regularly found myself monitoring and reflecting on how much time I had spent using linguistic resources from one named language, then (over-)correcting by spending long stretches of time using resources from the other. Seldom did I coordinate linguistic resources from these named languages and when I did it was because I deliberately chose to, which often felt somewhat contrived (e.g., Figure 7). And I frequently wondered whether my languaging practices disrupted socially and politically defined boundaries of named languages. I experienced this tension during each session of the program, *especially* thinking I was spending too much time using linguistic resources from English, creating few opportunities for Yesenia and Elio to use linguistic resources from Spanish. Still, I was committed to honoring Yesenia and Elio's bilingual practices and identities, and making the program a translanguaging space where they could freely leverage the linguistic resources associated with different named languages and gestures that comprise their full semiotic repertoires. Since the end of the program, my goal has been to continue developing my bilingual identity rooted in translanguaging, through enriching languaging experiences and tensions, and leave behind a hegemonic monoglossic perspective.

Just as I was committed to Yesenia and Elio's translanguaging, I also struggled with how to support Toben and Grace's translanguaging, especially through leveraging linguistic resources. I only shared linguistic resources associated with English with Toben and Grace, just like Yesenia and Elio, limiting the set of semiotic of resources we could leveraged when communicating and meaning-making. This small overlap in shared linguistic resources may explain why Toben and Grace did not use linguistic resources other than those associated with English (see Table 3, Figure 5). Moreover, when all students were present, all participants spoke English in order to include everyone at the table in the activities, which in turn may have decreased opportunities for Yesenia and Elio to translanguage through leveraging linguistic resources (see Figures 4 and 5). This raises the question: as researchers and educators, how can we support translanguaging spaces that include students who share linguistic resources from only one named language, and how can instructors support *all* students to engage in translanguaging practices? The answers to this question must account for the heterogeneity of emergent bilingual students as a group in the U.S., particularly the similarities and differences in their needs.

Implications for Science Education

This study's findings offer insight into some features of equitable science learning environments that can invite emergent bi-/multilingual students to experience Productive Disciplinary Engagement. First, centering modeling is a productive strategy for organizing science teaching and learning, inviting students to problematize the phenomena they observe by asking them to identify the "how and why" that give rise to their observations. Additionally, the inherent multimodal nature of modeling creates meaningful opportunities for emergent bi-/multilingual learners to leverage their full semiotic repertoires in the service of iteratively and collectively constructing mechanistic accounts (Grapin, 2019). Here, I have provided examples of the kinds of activities and materials that can support K-5 students to problematize the transmission and transformation of electrical energy in a circuit, transcending the simple conductor/insulator heuristic and problematizing what affects how much electricity flows through a resistor (see Appendix A). These learning activities invite emergent bi-/multilingual students to engage in epistemic practices that go beyond reading and/or writing about natural phenomena, as well as address the inadequate and simplistic science learning opportunities these students often experience.

Additionally, educators invested in equitable science teaching and learning must actively "desettle" normative expectations for science learning (Bang et al., 2012) and purposefully identify, value, and leverage bi-/multilingual students' translanguaging practices as important meaning-making repertoires in their own right (Bang et al., 2017). Science learning environments must leave behind the "narrow range (or repertoire) of ways of speaking, knowing, acting, and valuing" (Bang et al., 2017, p. 34), reflected on both teaching practices and curricular materials. A narrow set of valued resources preclude the kinds of translanguaging practices bi-/multilingual students bring to the learning environment, favoring more dominant forms of communicating knowledge about the natural world and interrupting opportunities for these students to participate in intellectually rich meaning-making (Rosebery et al., 2010).

Following the recommendations from García and Kleifgen (2019) on translanguaging pedagogies, desettling normative communicative expectations in science learning environments could be achieved through science educators providing students with multiple resources for engaging with and communicating their ideas about natural phenomena. To reiterate, however, these resources are not to be considered as temporary steppingstones towards more sophisticated forms of communication, but instead need to be valued and appreciated for their inherent epistemic forms and functions. Additionally, science educators must encourage students to collaboratively problematize phenomena, where groups engage in engage in translanguaging practices through drawing on their full semiotic repertoires, relying on spoken, written, gestural, and other meaningful resources. Even when educators' semiotic repertoires include linguistic resources associated with one named language (e.g., English), they can actively desettle normative forms of communication through sanctioning the use of resource from a broader semiotic repertoire. When it comes to evaluate student learning and participation, science educators must develop formative and summative assessments that encourage and attend to the ways students deploy their full semiotic repertoires to express their understanding. Finally, it is crucial that educators encourage students to reflect on their own ways of communicating and semiotic repertoires, particularly in relationship to how others share their thinking, such as scientists. Ultimately, the goal is for educators to support students to understand the sociopolitical realities of named languages and disciplinary discourses, while also empowering students to deploy their meaning-making repertoires in the service of co-constructing knowledge.

With this in mind, I offer two lines of inquiry that could help shed light on how to support equitable science education for emergent bi-/multilingual learners through centering heterogeneity. First, I think it will be important to investigate how to meaningfully incorporate aspects of disciplinary discourse into students' semiotic repertoires, without replacing other kinds of semiotic resources that students may find productive at various points of meaning-making. Again, there is no denial that the ways of communicating disciplines have developed for co-constructing knowledge are productive; we just need to remember that these discourses are informed by and used within sociopolitical contexts that tend to exclude minoritized communities. Finally, it will be crucial to investigate how to support K-5 science teachers be responsive to emergent bilingual students' translanguaging practices and support these students' science learning. Focusing on pre- and in-service teacher education is particularly important for both expanding their capacity to develop and enact equitable pedagogical practices and dispel common myths about how emergent bi-/multilingual students need to be remediated. As many have argued (Mazak & Herbas-Donoso, 2015; Poza, 2016; Stevenson, 2015), if our goal is to create equitable science learning environments that serve democratic purposes, where emergent bi-/multilingual students bring their whole selves to learning processes, we need to understand how responsive teachers can support science classrooms becoming translanguaging spaces.

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Appendix A

Enacted sequence of activities. (* indicates enacted sessions/activities that had to be revisited due to fluctuation in attendance; † arrived late to the session)

	Enacted Sequence of Activities		
	Session Title	*Investigation Question*	*Students in Attendance*
1	*Building Circuits w/ cables*	How can we use batteries and wires to turn the lamp on?	Non-consenting students
2	*Building Circuits w/ cables* *	How can we use batteries and wires to turn the lamp on?	Non-consenting students Toben and Grace
3	*Building Circuits w/ cables*	How do we think electricity is flowing through the circuit?	Toben and Grace
	Drawing Circuits w/ ink	How can we use batteries and the special ink to turn the lamp on?	
4	*Building Circuits w/ cables* *	How can we use batteries and wires to turn the lamp on?	Yesenia and Elio (arrived early) Toben and Grace
5	*Drawing Circuits w/ ink* *	How is it that using this pen makes the lamp turn on?	Yesenia and Elio
6	*Does electricity flow through all objects?*	Could all objects make the lamp turn on?	Yesenia and Elio
7	*Does electricity flow through all objects?* *	Could all objects make the lamp turn on?	Yesenia and Elio Toben and Grace
	Exploring R of ink I – length	What happens if we make these lines very long?	
8	*Exploring R of ink II – width*	What happens if we make these lines very thick?	Yesenia and Elio

Appendix B

Talk Moves I used to orchestrate discussion (adapted from Michaels and O'Connor, 2012).

Goals for Productive Discussions	Teacher Talk Moves	Pedagogical Strategy
Individual students share, expand and clarify their own thinking	Time to Think	Partner Talk Writing as Think Time Wait Time
	"Say More"	"Can you say more about that?" "What do you mean by that?" "Can you give an example?"
	"So, Are You Saying…?"	"So, let me see if I've got what you're saying. Are you saying…?"
Students listen carefully to one another	"Who Can Rephrase or Repeat?"	"Who can repeat what student just said or put it into their own words?" "What did your partner say?"
Students deepen their reasoning	Asking for Evidence or Reasoning	"Why do you think that?" "What's your evidence?" "How did you arrive at that conclusion?" "Is there anything in the text that made you think that?"
	Challenge or Counterexample	"Does it always work that way?" "How does that idea square with Sonia's example?" "What if it had been a copper cube instead?"
Students think with others	Agree/Disagree and Why?	"Do you agree/disagree? (And why?)" "Are you saying the same thing as her or something different, and if it's different, how is it different?" "What do people think about what that?" "Does anyone want to respond to that idea?"
	Add On	"Who can add onto the idea that Jamal is building?" "Can anyone take that suggestion and push it a little further?"
	Explaining What Someone Else Means	"Who can explain what she means?" "Who thinks they could explain that idea in their words?" "Why do you think he said that?"